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Dual regularization-based image resolution enhancement for asymmetric stereoscopic images

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Asymmetric stereoscopic imaging technique utilizes a pair of lower-resolution and full-resolution images to reduce the data storage requirement of stereoscopic images and videos, while maintaining fairly good quality in 3D perception. This paper proposes a resolution enhancement approach to reconstruct the original full-resolution image for this asymmetric stereoscopic system setup. The proposed approach exploits a dual regularization scheme: (i) a saliency-based regularization function is proposed to adaptively adjust the degree of regularization based on the local content of the image; and (ii) an occlusion-sensitive regularization function is proposed to exploit the correlation between the observed lower-resolution image and the observed full-resolution image in the neighboring view. Experiments are conducted to justify that the proposed approach outperforms a few conventional approaches.

1. Introduction

Asymmetric stereoscopic imaging technique is motivated by the psycho-visual studies of stereoscopic vision that the blur in a degraded image presented to one eye is masked by a sharper image presented to the other eye, without affecting perceived depth [1]. This masking characteristic has inspired many asymmetric image acquisition and image coding techniques, where one view image is sent with full quality, whereas the other view image is degraded by lowering the spatial resolution. Although this asymmetric stereoscopic imaging technique is good to reduce the bits required for storing stereoscopic images, a full-resolution image is required in many scenarios. For example, in the free view television, the user might get uncomfortable viewing experience if the lower-resolution view image is selected.

To reconstruct the original full-resolution image, one can exploit a spatially invariant image interpolation method [2] or edge-directed image interpolation algorithm [3–6]. However, they neglect the available observed full-resolution image in the neighboring view, which can provide more detailed information of the scene. Garcia et al. proposed to utilize the high-frequency information that is extracted from the neighboring full-resolution image to enhance the observed lower-resolution image [7]. This method assumes the true disparity information is available in advance; however, this disparity information might not be always available in real-world applications.

A dual regularization approach is proposed in this paper by exploiting both the observed lower-resolution image and the full-resolution neighboring view image. The proposed approach utilizes two regularization functions. First, a saliency-based spatially adaptive regularization scheme is proposed to adjust the degree of regularization adaptively for different regions of the image; this is in contrast to that a fixed degree of regularization parameter is imposed for the whole image in the conventional approaches. Second, due to occlusion and the accuracy of the disparity estimation

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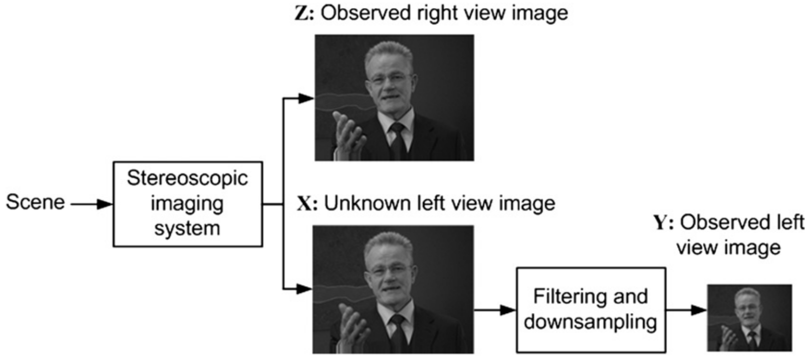

Fig. 1. An overview of image resolution enhancement for asymmetric stereoscopic images, where the aim is to reconstruct the unknown full-resolution image **X** using a pair of observed low-resolution image **Y** and full-resolution neighboring-view image **Z**.

method, there is potential to be large disparity errors presented in certain regions of the image. For that, an occlusion-sensitive regularization scheme is proposed to adaptively mark these regions so that they do not contribute in estimating the unknown full-resolution image.

It is important to note that the proposed approach is different from the conventional super-resolution image reconstruction approaches [8,9] in the following aspects. First, this paper address asymmetric stereoscopic images that have different resolutions. On the contrary, conventional image reconstruction approaches [8,9] use multiple lower-resolution image that are acquired from the same scene and yield same resolutions. Furthermore, in the context of this paper, there are only two images available, while there are usually N^2 images are available for an $N \times N$ enlarge ratio in conventional approaches. Second, the proposed approach aims to enhance the resolution of an observed image from a higher-resolution image, which is available in the other view and is supposed to yield more detail information of the scene. However, in the conventional super-resolution approaches [8,9], all the observed images are degraded (i.e., downsampled and blurred) versions of a single higher-resolution image.

The paper is organized as follows. Section 2 presents the formulation for the image resolution enhancement for asymmetric stereoscopic images. Then a dual regularization-based approach is proposed in Section 3. Experimental results are presented in Section 4. Finally, Section 5 concludes this paper.

2. Observation model

As depicted in Fig. 1, the given pair of stereoscopic images (say, with a size of $N_1 \times N_2$ each) are considered as the full-resolution ground truth. One view (say, right view) is observed with full resolution. The other view (say, left view) is degraded due to filtering and downsampling operations, and it is to be compared with the full-resolution image reconstructed from its lower-resolution counterpart (say, with a size of $M_1 \times M_2$ each) for conducting performance evaluation. To summarize mathematically,

$$\mathbf{Y} = \mathbf{DBX}, \tag{1}$$

where $\mathbf{Y}$ and $\mathbf{X}$ denote the observed low-resolution image and the original full-resolution image, respectively. Furthermore, both $\mathbf{Y}$ and $\mathbf{X}$ are represented in the lexicographic-ordered vector form, with a size of $M_1M_2 \times 1$ and $N_1N_2 \times 1$, respectively. $\mathbf{D}$ is the decimation matrix with a size of $M_1M_2 \times N_1N_2$, $\mathbf{B}$ is the blurring matrix of size $N_1N_2 \times N_1N_2$. On the other hand, denote $\mathbf{Z}$ as the observed $N_1 \times N_2$ full-resolution image in the neighboring view. With such establishment, the goal is to produce one full-resolution image $\mathbf{X}$ based on $\mathbf{Y}$ and $\mathbf{Z}$.

3. Proposed dual regularization-based image resolution enhancement approach

The proposed approach aims to estimate the reconstructed full-resolution image (denoted as $\hat{\mathbf{X}}$) using a dual regularization approach that exploits both the observed lower-resolution image and the full-resolution neighboring view image. The proposed approach utilizes two regularization functions: an intra regularization function and an inter regularization function. The intra regularization function is proposed to adjust the degree of regularization adaptively for different regions of the image, whereas the inter regularization function is used to adaptively mark these occlusion regions so that they do not contribute in estimating the full-resolution image. The proposed cost function is defined as

$$\hat{\mathbf{X}} = \arg\min_{\mathbf{X}} E_{total} = \arg\min_{\mathbf{X}} (E_{data} + \alpha E_{intra} + \beta E_{inter}), \tag{2}$$

where α and β are two regularization parameters to adjust the degree of regularization terms, respectively. The estimation of the reconstructed full-resolution image boils down to the definitions of three terms E_{data}, E_{intra} and E_{inter} in (2), which will be presented in the following three subsections.

3.1. Formulation of first term in (2)

The first term E_{data} represents the consistency between the observed low-resolution image $\mathbf{Y}$ and the reconstructed full-resolution image $\mathbf{X}$. According to (1), the observed image $\mathbf{Y}$ is considered as a down-sampled and blurred version of the unknown high-resolution image $\mathbf{X}$.